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A PARTICULAR CASE OF GLACIAL EROSION.[1]

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It is the purpose of this paper to describe a peculiar phase of glacial work, where a layer of stratified rock of considerable area was shoved forward bodily on its bed, and then thrust up out of horizontality. Use is made of this case to explain the manner in which a number of other known dislocations of bed-rock in the vicinity might have been made, as well as to explain how glaciers in general may affect the subjacent rocks under certain circumstances. The present illustration is found near the University of Minnesota, in Minneapolis, about a mile below the Falls of St. Anthony, on the east side of the gorge of the Mississippi. The conspicuous feature of the displacement is represented in the right (southeast) half of the accompanying profile (Fig. 1). The left (northwest) half of the profile is drawn from notes, aided by photographs taken from time to time as ground was excavated in a stone quarry, which has been working obliquely across the line of the profile. The line of the profile corresponds with the direction of glacial movement. There is also, at the time of writing, an exposed section parallel to and corresponding with that of the left half of the figure.[2]

The section which is represented by the profile (Fig. 1) lies near the 800-foot contour line as established by the topographic map.[3] As shown on the map, a terrace lies between the 780 and 800-foot contour. This terrace belonged to the Mississippi River at a stage when the falls were below this point, instead of above it, as they now are. Besides the terrace contour, the occurrence of the river shingle and well-preserved shells of species of *Unio* shown at *R* (Fig. 1), under a layer of peat (*P*), proves that the river once flowed over the site. The glacial drift has not, therefore, its original thickness. Twenty feet or more of it have been washed away by the river, and should be restored in interpreting the glacial work in this particular case. In other respects, the accompanying profile explains itself in the main. Below the soil and peat (*P*) is terrace sand, *T*, with the shells of land snails, *Helix*, *et al.*, in it, and the river shingle, *R*, with *Unio* shells. Still lower is the glacial till, G_1 and G_2, overlying beds of the Galena (Trenton) series. Of these, the first (lowest) bed, B_1, and the second, B_2, are massive limestones. The lower part of the third bed, *Sa*, is also limestone, but is distinguished by its color, and hard, pyritiferous, crystalline condition. The upper part, *Sb*, consists of several layers of grayish crystalline limestone, separated by uneven clay-shale seams. *Sc* (at the right of Fig. 1) is clay-shale, overlain by limestone, *d*, belonging to the same third bed. *Sa* to *Sd* comprise about half of the third bed of the series, as seen elsewhere in the vicinity. The upper part, here wanting, is shale, with thin and widely separated layers of limestone.

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[1] This paper was read before the Minnesota Academy of Sciences, January 3, 1905.

[2] Observations on this exposure have extended over several years. Negatives taken are on file in the Department of Geology, University of Minnesota.

[3] St. Paul quadrangle, U. S. Geological Survey.

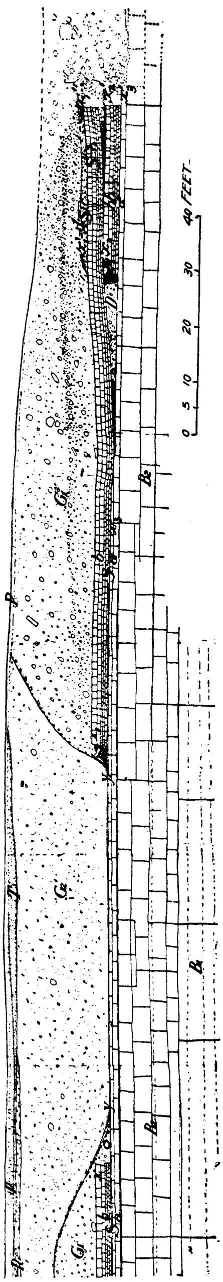

FIG. 1.—Profile showing glacial action from left to right. Strata thrust up on the right or front, and pulled apart on the left. B_1 and B_2, massive limestones; *Sa* to *d*, limestones and shales; G_1, older drift; G_2, newer drift; *X* to X_3, older glaciated surface, broken; *Y* to Y_1, newer glaciated surface; *R*, river shingle; *T*, terrace sand; *P*, soil and peat. Vertical and horizontal scales equal.

On the right (southeast) of the section there are three remarkably glaciated surfaces, X_1 (top of *Sb*), X_2 (top of *bb*), and X_3 (base of *bb*), one above the other. It is this phenomenon, noticed more than ten years ago, which led me to study this locality. At that time the part of the profile which is represented in broken lines was exposed by quarrying, while the rest was concealed. This part, represented in broken lines, is drawn from memory.

The part of the section shown in the right half of the profile was exposed several years later, and showed that the glacial movement was from the westward, not from the eastward or southeastward, as was originally supposed. Only during the past year has the left half, as represented in the profile, been cut across in such ways as to reveal the two drift deposits, G_1 and G_2, as well as the undisturbed part of the stratum *Sb*.

It is now evident that the newer till, marked G_2, represents the position of the ice which forced the stratum *Sb* apart, and shoved the one part, *Sb*, with its overlying drift, G_1, from X to X_1. At the same time, the surface between Y and Y_1 was scratched, though not much worn. The glacial deposit G_1 is older than G_2, though the two are in contact. They are essentially alike, though the proportion of pebbles is greater in one than in the other, and the boundary between them is structurally well marked.

The mass of shale and limestone which was moved forward rests on the surface of a stratum which, from Y_1 to X_3, is not glaciated or cut, being protected by a clay lamina, while from X_3 to X'_3 the surface below the shoved block is glaciated, and one thin layer, for the greater part of the distance, has been ground away. In the undisturbed strata at the left (northwest) there is a clay-shale lamina at the base of *Sb*, and it is the lowest of several such partings between the limestone layers. The disturbed mass started to move upon the lowest shaly lamina, and was driven out over a denuded or already glaciated surface X_3 to X'_3.

All the glaciated surfaces, excepting that which is indicated by Y to Y_1, were originally one, running from X on the left, along X_1, to X''_1, which was originally continuous with X_2 and down along X'_3, as we see if we imagine the disturbed strata put back in place. Then with the second till, G_2, eliminated, we obtain the conditions which preceded the movement. In this it will be noted, further, that the interval or gap, from X to X_1, on the left, which should represent the distance traveled, is less than the distance from X_2 to X'_2 plus that from X_3 to X'_3, which should also represent the distance traveled.

Before this relation is explained it should be noted that the drift-wedge, marked *D*, represents a clay-shale and till intermixture entrapped under the upturned strata.

To explain how the block *bb* came to lie under the main block (*Sb*) in the section, the following details are given. The major joints in the rock strata run generally in north-to-south and east-to-west directions. The glacial movement was oblique to those directions, in this case, from the northwest, and the blocks were therefore driven in a diagonal direction. A side thrust may have been given as the one sheared upon the other. The under part or block, *bb*, also probably rotated in front of the drift, *D*, as it shoved forward. As the result of the rotation, the distance traveled by the mass seems greater than it probably was. On the other hand, the distance of the gap, Y to Y_1, owing to the direction of glacial movement not being exactly diagonal to the blocks, may be a little shorter than the whole distance traveled.

The most conspicuous feature in the exposed section—viz., the disjoined under block, *bb*—is not the matter of first importance. Its position is incidental, as is shown by comparison with another part of the same mass, which still lies on the other side of the boulevard. In this there is normal drift merely, in place of the block, *bb*, and the larger body of limestone has moved upward quite the same.

One feature of special significance is the upturned front of the transported mass of limestone and till. Altogether, the front appears to have the shape of the point of a spoon. Another significant feature is the abrupt disjoining of strata at the rear. The strata were pulled apart. These features appear in other occurrences. In other exposures, beds of clay-shale and included limestones, now in place, are seen to end abruptly against the glacial till, as the stratum *Sb* does on the left of this section. One such exposure which is to be seen at the time of this writing is in another quarry, half a mile to the southeast of the locality of the section shown in Fig. 1, on the west bluff of the river. Here the clay-shale beds, some 10 feet thick, are cut off nearly vertically by the till, the latter lying on the leeward side in relation to glacial movement. Several other similar occurrences have been seen in the vicinity. They differed, however, in having the abrupt end of the clay-shales more or less sloping.

The two chief features in this case were, I think, formed under the following circumstances: At an early stage, glacial erosion cut the stratified bed-rock unevenly, so that, when deposited, the till, G_1 rested at the left on the clay-shales, *Sc* (now shoved over to the right), in the middle on the limestone with shaly seams *Sb*, and toward the right on the limestones *Sa* and B_2. The later ice-movement was over the till G_1. Its friction with the till produced stress, which was transmitted to the stratified rocks, and they yielded along the lowest clay-shale seam, moving forward. The initial disjoining of the stratum (*Sb*) and the till $(G)_1$, may be ascribed to unequal stress from unequal friction of the glacier on its bed. After the gap began to open, the ice settled into it, while the rock-mass was moving forward. The upward thrust in front and the gap at the rear may be correlated through a compensating movement in the glacial ice, as illustrated in Fig. 2. In this diagram the original position of the ice, the older drift, and the subjacent stratified rocks are represented in solid lines, while the result of the movement is indicated by broken lines and dots. Ice filled into the gap, *L*, as the drifted mass *M* tended to fill the position at *O*, in its stead. The horizontal line (1–2) indicates the original direction, while the other (3–2) indicates the subsequent direction, and the angle (1–2–3) the relative rotation of the ice-mass in compensating.

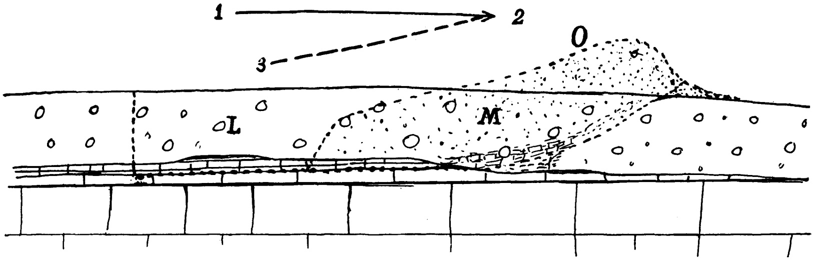

FIG. 2.—Diagram showing change of direction of ice-movement from 1–2 to 3–2 as the mass *M* moves from *L* toward *O*. Original position of ice and subjacent rocks in solid line; change by movement, in broken lines.

Whether this work of the glacier was done far from or near to the front of the ice-sheet does not appear. The reason why the drifted mass stopped where it is now seen is also not evident, and may be a very incidental matter. Notably, however, the manne in which a start could have been made by those masses which were carried much farther, is shown.

It may also be argued that a series of masses could, under repeated cause, lodge one behind the other. An explanation for the entrapped drift-wedge, *D*, in the section (Fig. 1) may be that the block *bb* was set forward, and a gap behind it filled with till before the main mass started. As to general application of this particular case, any mass of till, resting on a lamina of clay, might be started and then rotated forward in like manner; but with no stratified rocks as a distinctive mark, such cases might be difficult to interpret.

Evidence tending to prove that the glaciers have elsewhere plowed up the bed-rock of the region is not rare. It has been seen in the excavations for buildings, stone quarries, and road-gradings in Minneapolis and St. Paul, where the underlying rock is of Ordovician age, and is exposed along the gorge of the Mississippi. Elsewhere it is generally concealed by the glacial drift. In these exposures, blocks of limestone are often seen scattered or grouped in the bowlder-clay, as if the rock had been torn up in large masses, and are so exactly like the rock which exists *in situ* in this region as to be unmistakable. While they might have come from miles away, so far as the kind of rock is concerned, they are more probably torn from the sides of preglacial valleys now buried under the glacial deposits in this vicinity. Of more particular importance here are certain clay-shale masses which occur in the bowlder-clay. By the character of the clay and of the included lenticular masses of crystalline limestone, and by the contained fossils, the original position of these clay-shale masses may be determined. One or more of the beds whence they came are still in place over a great part of this area, under the drift and above the limestone. The shale-masses in the drift have presumably been torn up not many miles from the place where they now lie.

These drifted clay-shale masses are generally not weathered, and retain their original blue color. They are often unmixed with pebbles of northern drift, and in a few cases they retain their original stratification, as well as their fossils. Small masses are most common and least distinct. The largest are 100 feet or more in horizontal diameter, and 50 feet or less thick. They generally have upturned fronts, which are also relatively more disrupted than are the rears. As an example I may mention an occurrence in St. Paul, already briefly described.[1] At that place a mass of shales, representing recognized beds of the Galena (Trenton) series, covers about an acre of surface. As shown in the grading of the streets which cross it, the shale is surrounded by northern drift, which lies over part of it, and probably under all of it. Other cases of similar import were cited in the article referred to.

The manner in which the glacier transported these large masses, without overturning them, was a matter of wonder until the discovery of the case here described. This particular occurrence shows at least how the great clay-shale masses may have been plowed up.

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[1] *Journal of Geology*, Vol. VI, p. 688.